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TECHNICAL NOTE

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STRENGTH OF FILAMENTARY SHEETS WITH ONE

OR MORE FIBERS BROKEN

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SUMMARY

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Experimental static-stress-concentration factors at failure for a filamentary material containing unidirectional dacron fibers and subjected to tensile loads are presented and compared with previously published theoretical results. The favorable agreement of the theoretical and experimental results indicates the theory is valid for the static-load case.

INTRODUCTION

Structures fabricated from filamentary materials are finding many applications in aerospace vehicles. Whenever one or more filaments are broken in such structures, as might occur from material imperfections or collision with flying objects, tensile loads must be transferred from the broken fibers to adjacent fibers of the structure. Although the problem of stress concentrations in the vicinity of discontinuities in homogeneous materials has received considerable attention in the past, fundamental differences in the particular case of filamentary materials require special treatment. An example of such special treatment is contained in the theoretical analysis given in reference 1, where the stress concentrations which occur in fibers adjacent to one or more broken fibers of a filamentary model were obtained. The model considered in reference 1 consists of uniform unidirectional tension-carrying filaments imbedded in a uniform matrix which transmits only shear. Both static and dynamic results were obtained analytically within the limits of small-deflection elasticity theory.

In order to provide an experimental evaluation of the static results given by the theory of reference 1, a test program of a filamentary material was undertaken and the results are presented herein.

SYMBOLS

K_r static-stress-concentration factor of fiber adjacent to cut or broken fibers

n total number of fibers

P	maximum load of specimen with one or more cut fibers, lb
p	load per fiber at failure, lb/fiber
p_u	ultimate strength per fiber, lb/fiber
r	number of cut or broken fibers

Superscripts:

n	finite number of fibers
∞	infinite number of fibers

MATERIAL AND TEST SPECIMENS

A filamentary material with uniform unidirectional fibers and with essentially elastic behavior in tension was desired because of the limitations of the theory of reference 1. In addition, it was desired that the material be essentially elastic to failure, since stress-concentration factors at failure may be easily obtained in the case of filamentary materials. These requirements are desired because of the supposition that the fibers adjacent to a cut in a filamentary sheet will fail at their individual fiber strengths, which are known or may be obtained from separate tests in which stress raisers are not present. The stress-concentration factor at failure then is given simply by the ratio of this individual fiber strength to the average stress per fiber on the net section at rupture of a filamentary sheet containing a stress raiser such as a cut. The material selected for the test program consists of one layer of uniform unidirectional dacron fibers imbedded in a matrix of polyurethane elastomer and backed on one side with a one-half-mil Mylar film. Details of the material are given in figure 1 along with a load-strain curve for the material in tension, which indicates the degree of elastic behavior.

Tensile strips, as indicated in figure 2, were cut from the filamentary material. The strips were partially slit transversely at midlength with a sharp-edged blade, and the slit length varied such that strips containing one to six severed fibers were obtained. In each case the adjoining matrix and Mylar backing were severed along with the fibers. Two strips of each slit length were made which resulted in the total of twelve strips in the program. Each strip contained 15 continuous fibers on each side of the slit so that there were 30 continuous fibers at the cut section and from one to six cut fibers. The strips were made 36 inches long (the maximum allowed by the testing machine) to permit the matrix to transmit shear loading such that a uniform tensile loading was approached at a distance from the cut. Filamentary reinforced tape was attached to both sides of each end of the specimens as indicated in figure 2 to protect the ends of the specimens from the knurled surfaces of the grips and to distribute the load such that failure did not occur at or near the grips.

Material Composition

Filaments: 1200 denier type 52 dacron polyester fibers with 1.5 twist per inch. Nominal value of 40 parallel fibers per inch.

Matrix: Adiprene L–100 polyurethane elastomer cured with 11 parts per hundred of diamine.

The material also contains a one–half–mil Mylar film backing on one side.

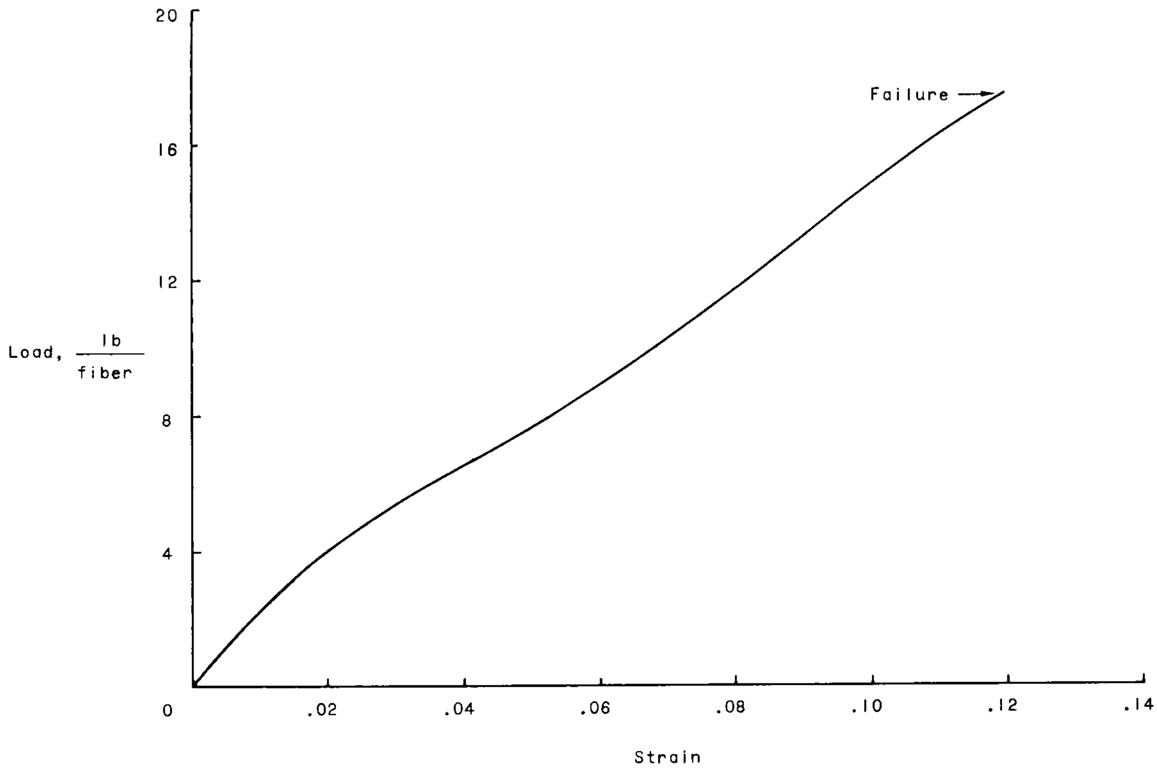

Figure 1.- Load-strain curve and material composition for filamentary material.

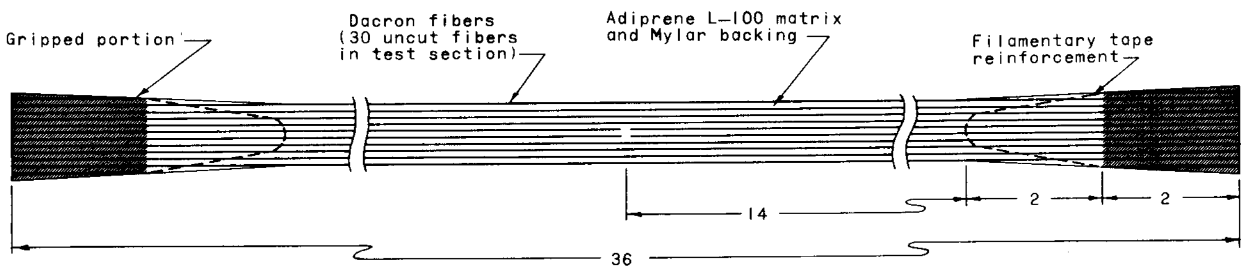

Figure 2.- Details of test specimens. All dimensions are in inches (specimen shown with two fibers cut).

METHOD OF TESTING

The specimens were tested in tension by using a hydraulic testing machine with a capacity of 100 kips. (See fig. 3.) Two inches of each end of the specimens were placed in Templin grips and after careful alinement were subjected to tensile loading at a strain rate of about 0.02 per minute until failure occurred. The ultimate strength of the filamentary material used in this experimental investigation was determined from tests of two separate samples of the material cut from each of the previously tested strips containing the cut fibers. The samples were 6 inches in length and were taken at approximately the quarter points of the original strips. Two inches of each end of the 6-inch samples were placed in hard-rubber-faced grips of an Instron testing machine such that the test length between grips was 2 inches. These samples were loaded to failure at a strain rate of about 0.05 per minute to obtain the ultimate strength of the strips in the absence of stress concentrations provided by cut fibers. Figure 4 shows a typical load-strain curve obtained from one of these samples. A comparison of figure 4 with figure 1 indicates a slight improvement in linearity of the load-strain curve for the samples of the material because of the prior loading; however, as might be expected, the strengths are in agreement within the variation associated with the material.

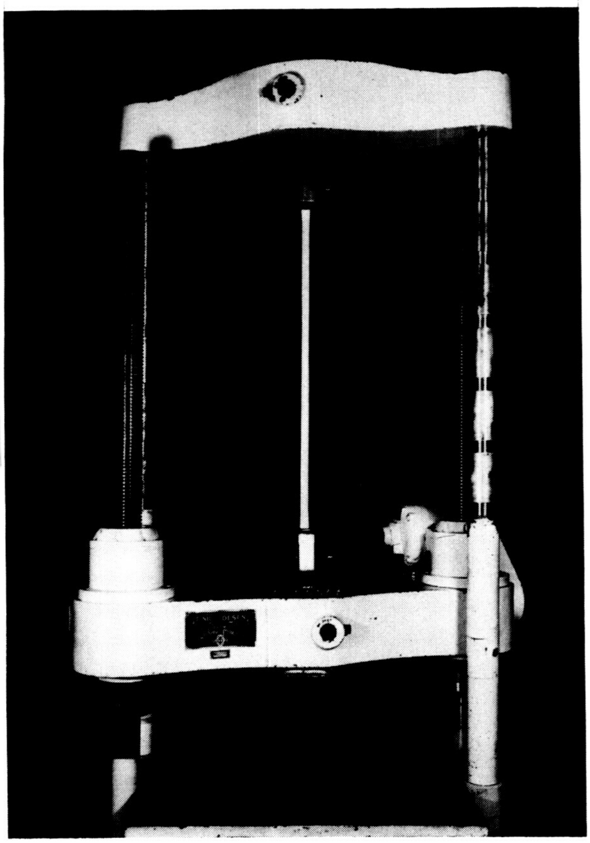

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Figure 3.- Tension test of filamentary material.

RESULTS AND DISCUSSION

Results of the filamentary-material tests are given in table 1. The maximum load obtained for each of the strips containing one or more cut fibers is listed under the column headed P. The column headed p shows the average load per fiber at failure obtained by dividing P by the number of continuous fibers (30) at the cut section. The column headed p_u shows the average ultimate fiber strength of the two samples of material taken from each specimen as previously mentioned. Two of the ultimate-strength samples varied from their average by 8 percent, but the remaining ones varied by less than 4 percent from the individual averages reported. The final column of table 1 is the stress-concentration factor K_r^n defined as the ratio of the ultimate fiber strength p_u of the material to the average load per fiber at failure p for the specimens containing cut fibers. This definition of the stress-concentration factor is consistent with that normally used for homogeneous materials and corresponds to that defined in reference 1 for the case of an infinite number of fibers.

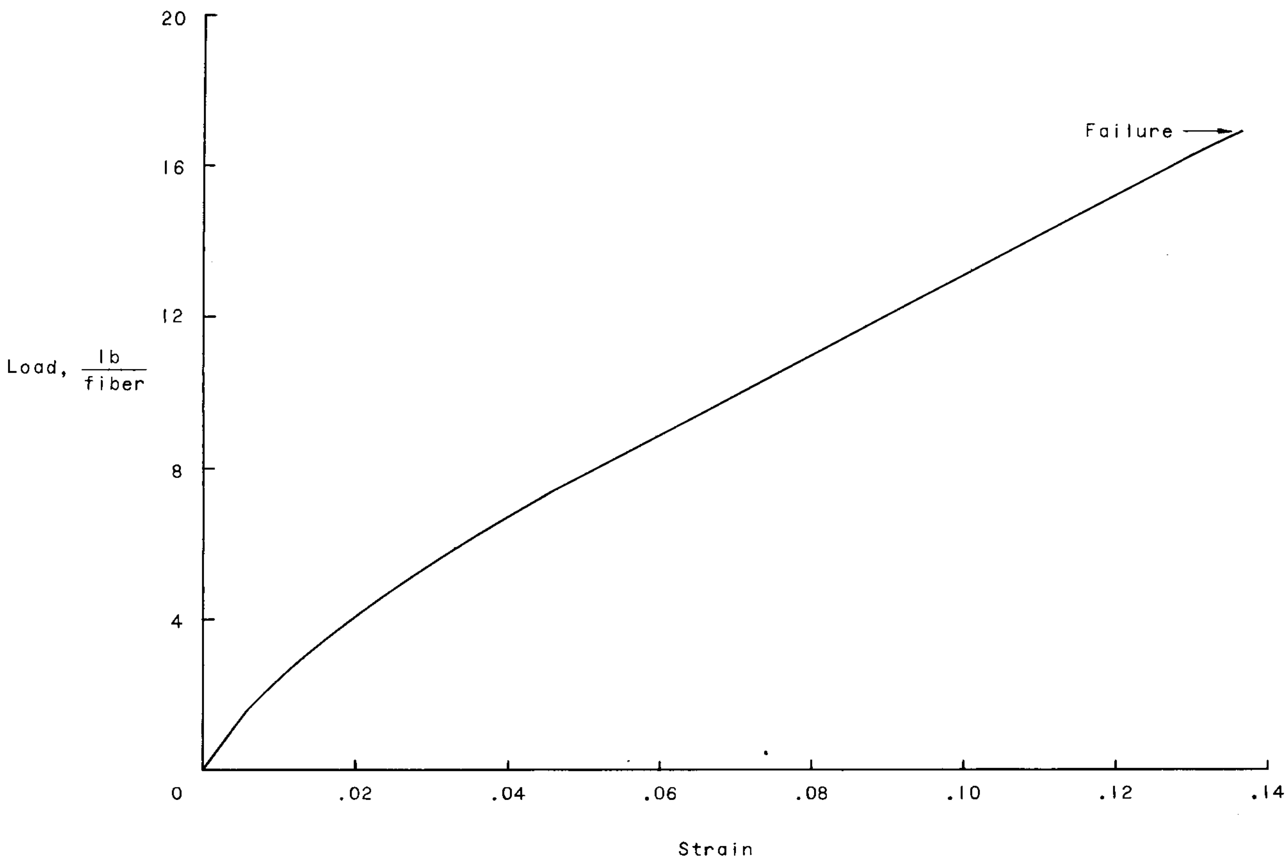

Figure 4.- Typical load-strain curve of sample of previously tested filamentary material.

The stress-concentration factors given in table 1 are shown by the symbols in figure 5 for the number of cut fibers. Also shown in figure 5 by the solid curve are the theoretical stress-concentration factors given by reference 1. Figure 5 shows that the stress-concentration factors obtained experimentally are in favorable agreement with the theoretical values. It is noted, however, that the test data tend to underestimate the theory for the larger number of cut fibers. This disparity is attributed largely to the finite number of fibers which exist for the experiments whereas the theory assumes an infinite number. The theoretical case for a finite number of fibers has not as yet been solved, and although such a solution would be of value for the laboratory tests reported herein, the results for an infinite number of fibers should be of more interest for filamentary structures in general. A qualitative indication of the effect of a finite number of fibers may be obtained by applying the method given in reference 2 for obtaining the stress concentrations for a plate of finite width from the stress concentrations for an infinite-width plate. Although the method suggested in reference 2 for a homogeneous plate is not directly applicable for filamentary materials, an indication of the proper trend may be obtained. The equation of reference 2 used to obtain the stress concentrations for a finite number of fibers from the infinite-fiber results is

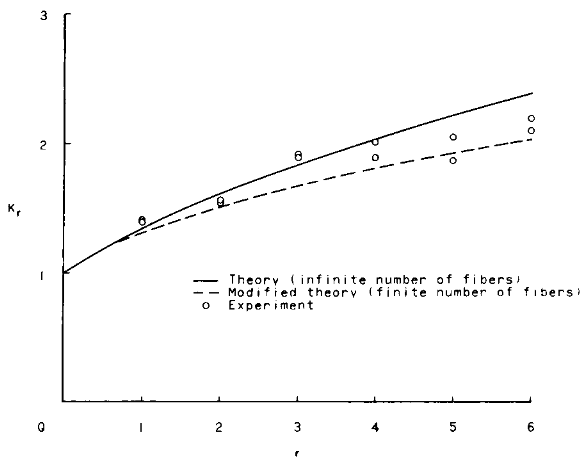

Figure 5.- Comparison of theoretical and experimental stress-concentration factors.

$$\frac{K_r^n}{K_r^\infty} = \sqrt{\frac{1 - \frac{r}{n}}{1 + \frac{r}{n}}}$$

where the symbols have been arbitrarily changed to apply to the filamentary case. The values of K_r^n obtained when this equation is applied to the theoretical stress-concentration factors for an infinite number of fibers are shown by the dashed curve in figure 5. The agreement of the test data with the dashed curve supports the reasoning that the disparity of the solid curve and the test data for the larger number of cut fibers is principally due to the finite number of fibers in the experiments as opposed to the infinite number assumed theoretically.

Some of the difference between theory and experiment shown in figure 5 may also be attributed to the particular values of ultimate strength of the fibers (p_u in table 1). It is well known that the strength of fibers is affected by the length, and the particular length to be used in obtaining the values of p_u may be questioned somewhat. The cut fibers induce the adjacent fibers to fail in the vicinity of the cut and the chances are that such location is not the weakest portion of the fiber. Therefore, the correct value of p_u for the experimental cut strips may be somewhat higher than the values obtained from the 2-inch test samples.

CONCLUDING REMARKS

Experimental static stress-concentration factors at failure for a filamentary material have been presented and are in close agreement with a theoretical analysis. Future work should be directed toward verifying theoretical results for dynamic overshoot and evaluating the stress-concentration factors associated with laminates containing multidirectional fibers.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., December 26, 1962.

REFERENCES

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2. Dixon, J. R.: Stress Distribution Around a Central Crack in a Plate Loaded in Tension; Effect of Finite Width of Plate. Jour. R.A.S., vol. 64, no. 591, Mar. 1960, pp. 141-145.

TABLE 1

EXPERIMENTAL RESULTS OF FILAMENTARY-MATERIAL TESTS

r	P, lb	p, lb/fiber	p_u, lb/fiber	K_r^n
1	350	11.67	16.27	1.39
1	329	10.97	15.52	1.41
2	300	10.00	15.38	1.54
2	287	9.57	14.97	1.56
3	254	8.47	16.05	1.89
3	256	8.53	16.42	1.92
4	247	8.23	16.57	2.01
4	254	8.47	16.01	1.89
5	226	7.53	15.47	2.05
5	248	8.27	15.47	1.87
6	226	7.53	15.81	2.10
6	222	7.40	16.28	2.20

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